

Top Results from the Tevatron

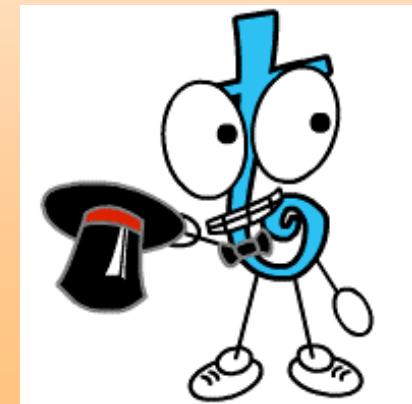
Andrew Ivanov
University of California, Davis
for the CDF and D0 Collaborations



Aspen Winter Conference
February 13, 2006

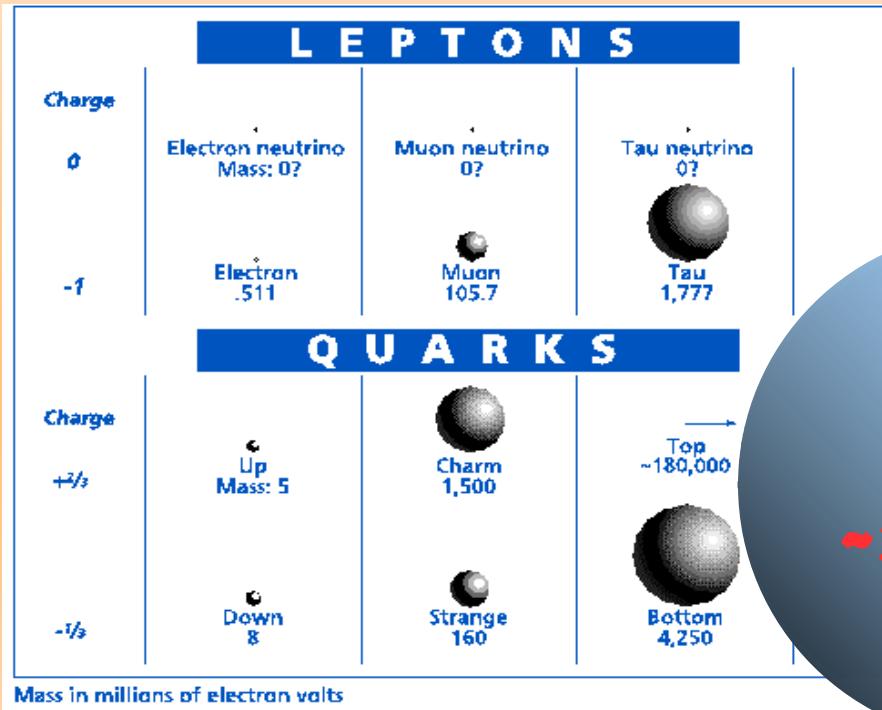
Top Quark

- Discovered in 1995 at Tevatron
- Youngest member of the quark family
- “Last brick” to the Standard Model



- Not a surprising discovery:
b-quark requires isospin
partner, however ...

Why is the top quark so special ...



- Unexpectedly huge mass
- Comparable to gold nucleus

TOP
~175 GeV

$$y_t = \frac{\sqrt{2}m_t}{v} \approx 1$$

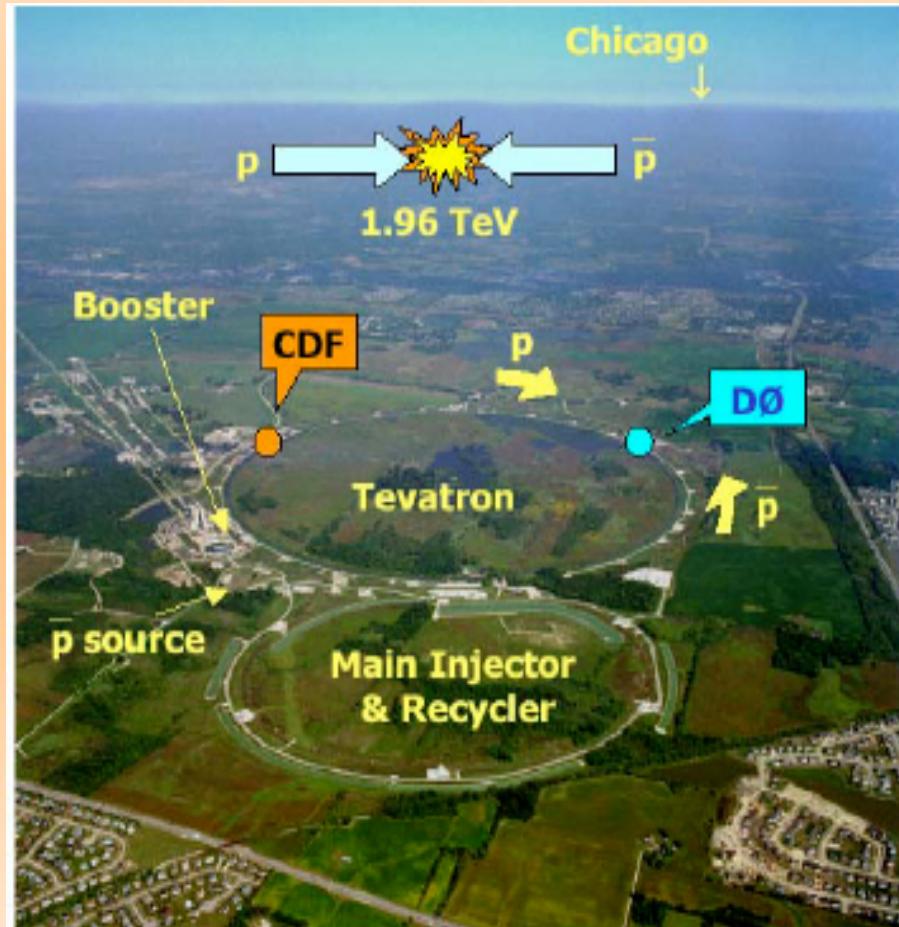
- Special role in the dynamics of EWSB ?
- Serves as a probe of BSM physics

$$\tau_{\text{top}} \sim 10^{-24} \text{ s}, \quad \Gamma^{-1} \approx (1.5 \text{ GeV})^{-1} \ll \Lambda_{\text{QCD}}^{-1} \sim (200 \text{ MeV})^{-1}$$

- Decays before hadronizing
- Passes momentum and spin info to its decay products

Tevatron Collider

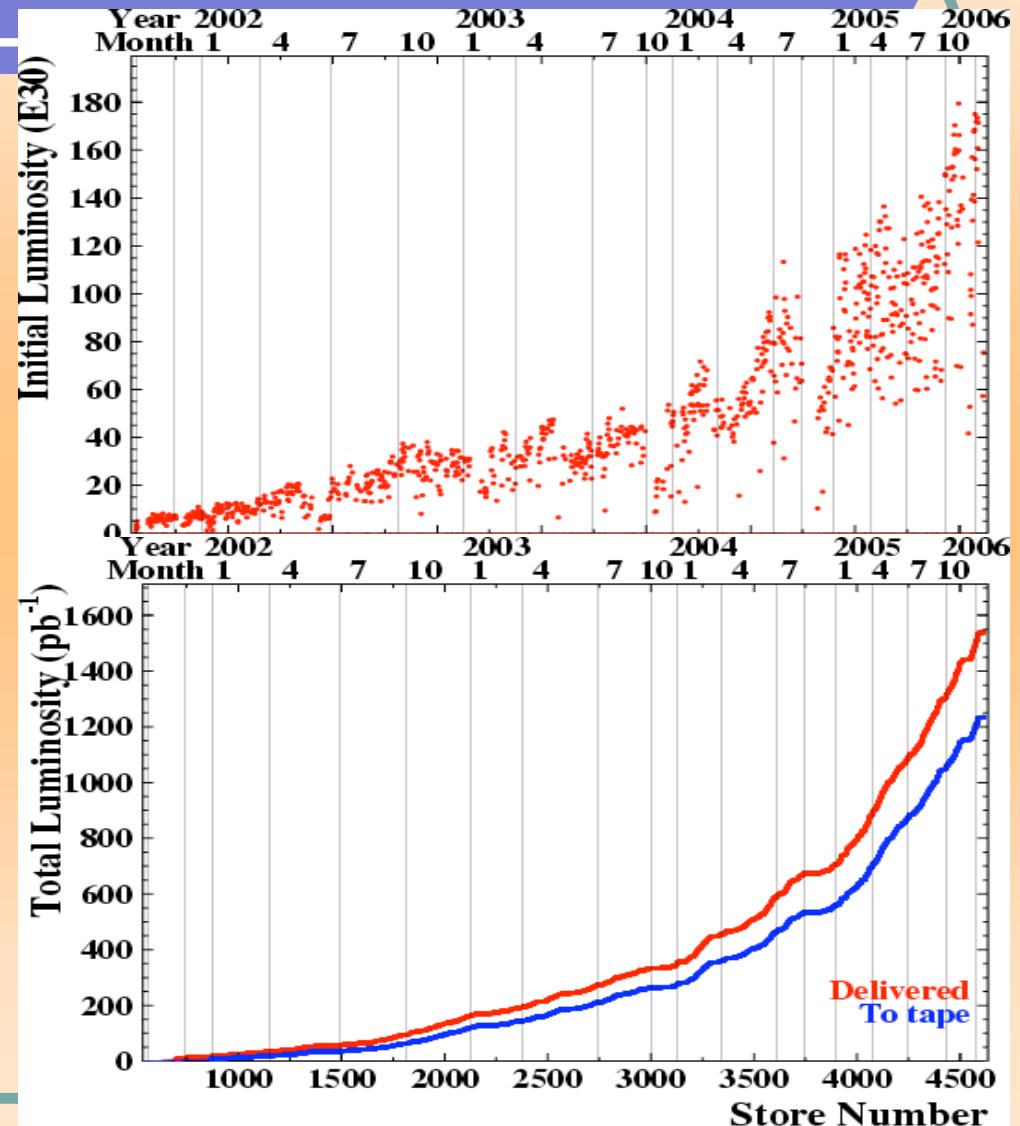
- Currently the world's only top quark production machine
- Operating at world's highest particle energy collisions
- Run I (1992-1996)
 - $\sqrt{s} = 1.8 \text{ TeV}$
 - Integrated Lum $\sim 110 \text{ pb}^{-1}$
 - Top Discovery!
- Run II (2001-present)
 - $\sqrt{s} = 1.96 \text{ TeV}$
 - 30% higher $t\bar{t}$ cross section
- Two multi-purpose detectors



Luminosity in Run 2

Record initial Luminosity
 $1.79 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
(11/10/2005)
On tape $\sim 1.2 \text{ fb}^{-1}$

- I will concentrate on the latest results with up to $\sim 760 \text{ pb}^{-1}$
- Some of analyses presented here with $\sim 360 \text{ pb}^{-1}$

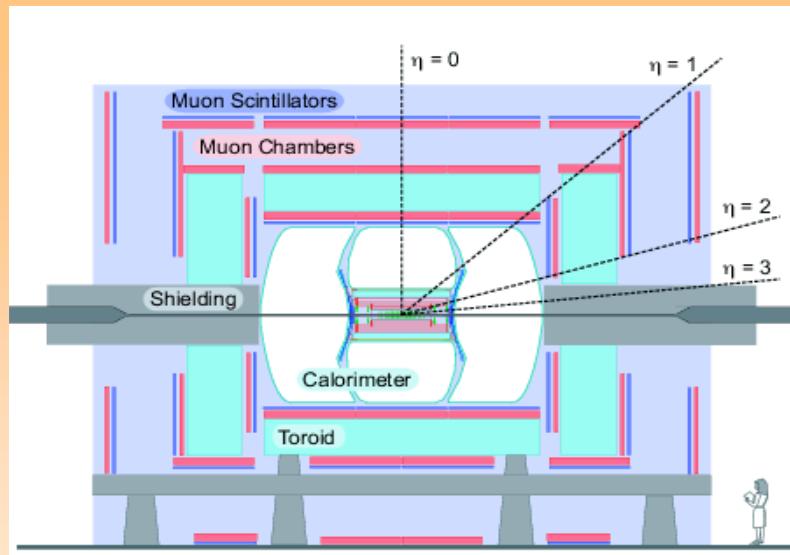
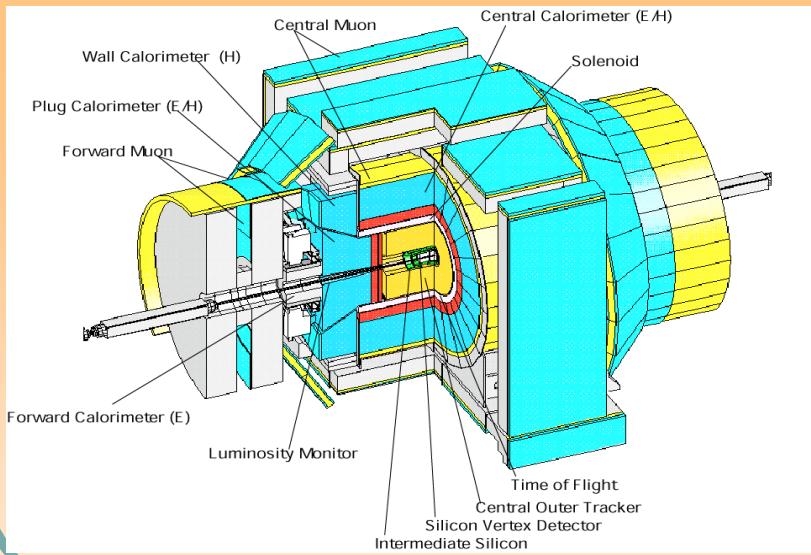


Tevatron Detectors

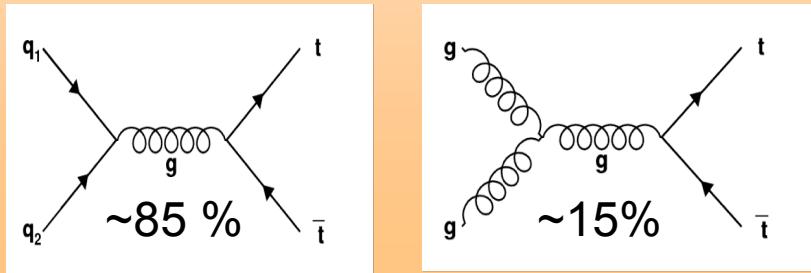


- Inner Silicon Precision Tracking
- Tracking Chambers
- Solenoid
- EM and HAD calorimeters
- Muon Detectors

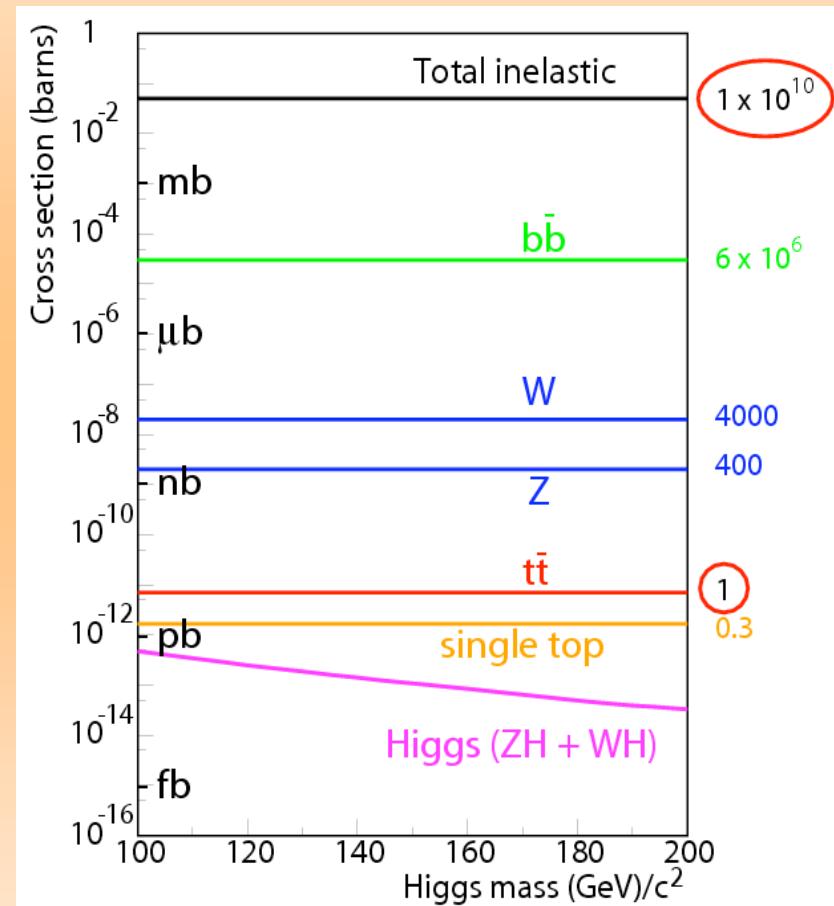
All crucial
for top physics!



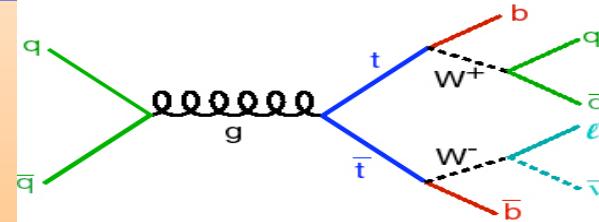
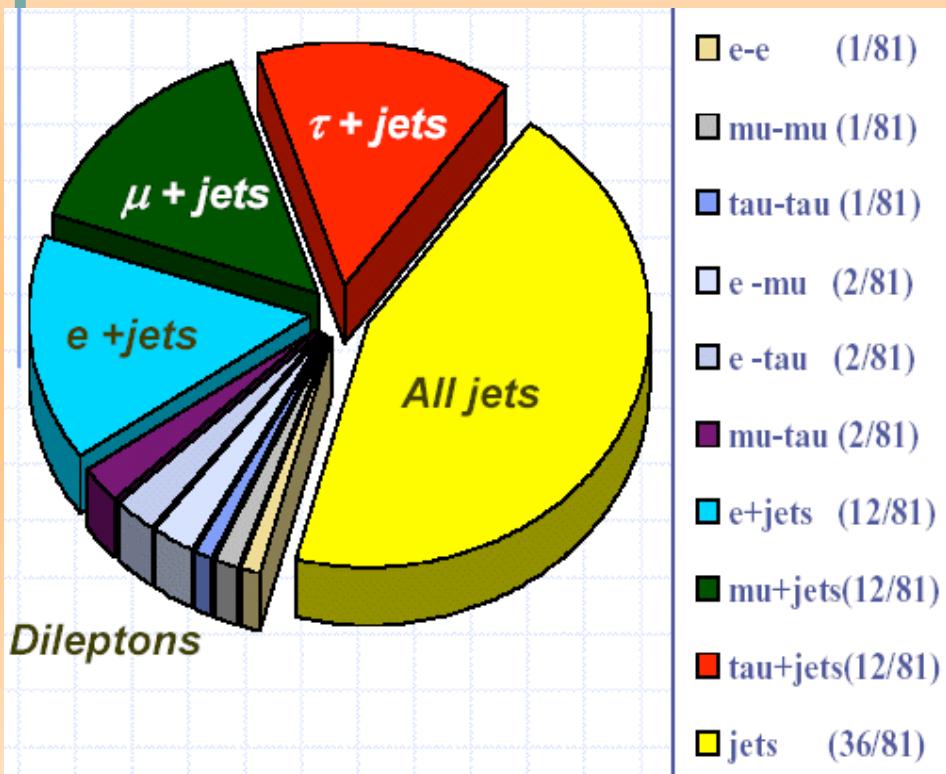
Top Quark Production



- Within SM
- $\sigma_{tt} = 6.7 \text{ pb}$ @ $m_{\text{top}} = 175 \text{ GeV}$
- One top pair every 10^{10} inelastic collisions

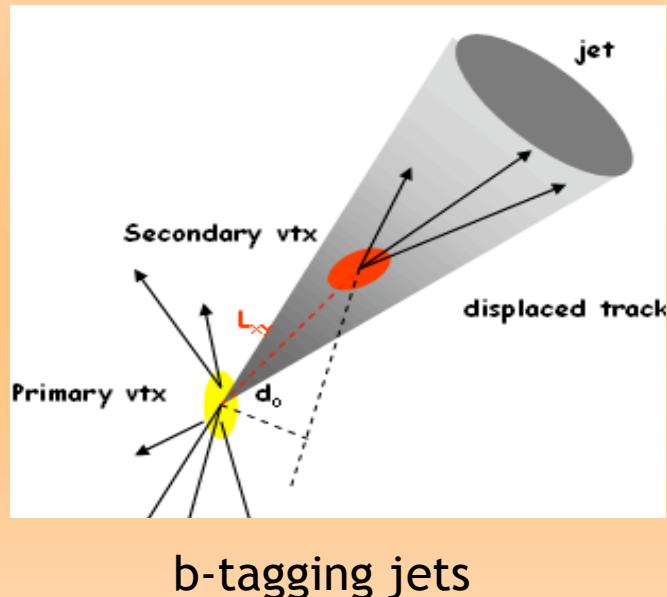


Top Quark Decay



- $t \rightarrow Wb$
- Events classified by W decay
 - LJ: “Lepton [e, μ] + jets” (30%)
 - $tt \rightarrow bl\nu b\bar{q}q'$
 - DIL: “Dilepton [e, μ]” (5%)
 - $tt \rightarrow bl\nu bl\nu$
 - HAD: “All jets” (44%)
 - $tt \rightarrow b\bar{q}q'b\bar{q}q'$
 - “Tau + X” (21%)

Detecting the Top



- Signal:
 - Triggering on lepton
 - High missing transverse energy (\cancel{E}_T) in LJ/DIL modes
 - High E_T jets, central and spherical
 - Two b-jets (displaced vertex)
- Background:
 - W+jets: dominant in LJ (less central/energetic), fakes DIL
 - DY(dileptons): no \cancel{E}_T
 - QCD: huge in HAD mode

Production Cross Section Measurements

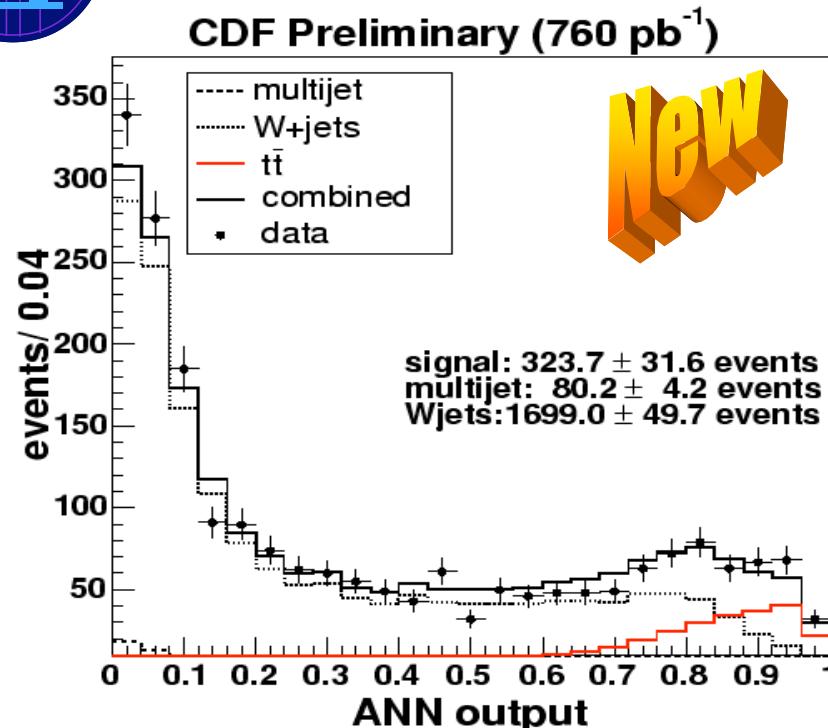
$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bgd}}{\varepsilon_{t\bar{t}} \cdot \int L dt}$$

- Testing non-standard model top production mechanisms
- Top sample might contain an admixture of exotic processes

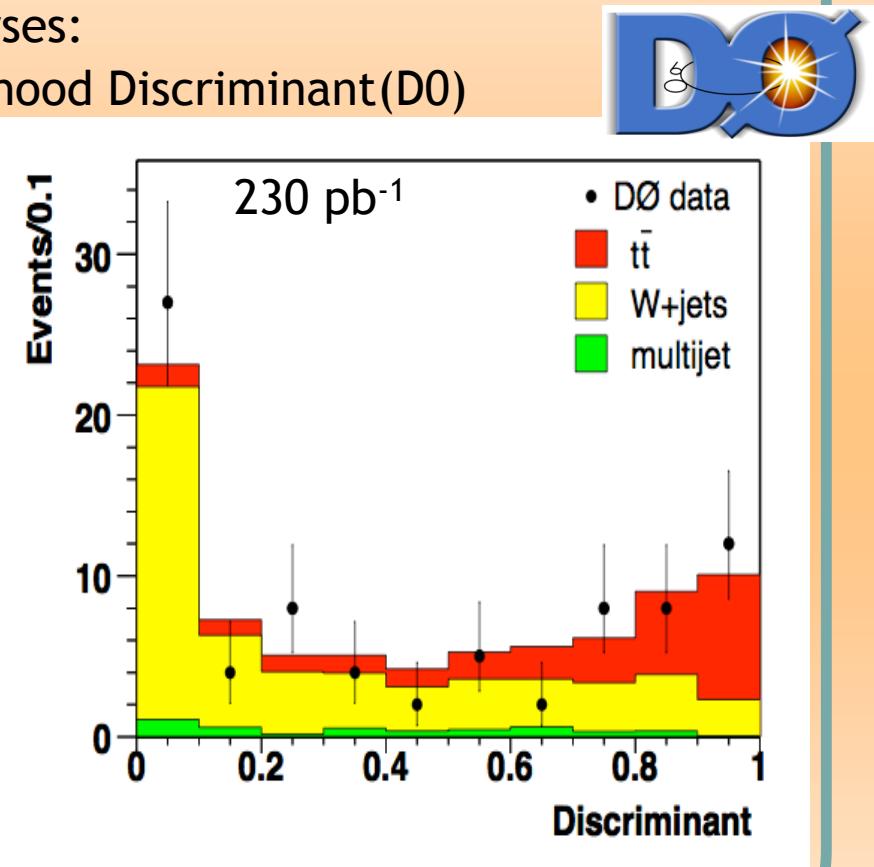
Lepton+jets cross section



- Topological/kinematical analyses:
- Neural Network (CDF) / Likelihood Discriminant(D0)



$$\sigma = 6.0 \pm 0.6 \text{ (stat)} \pm 1.0 \text{ (syst)} \text{ pb}$$



$$\sigma = 6.7 \pm 1.4 \text{ (stat)} \pm 1.4 \text{ (syst)} \text{ pb}$$

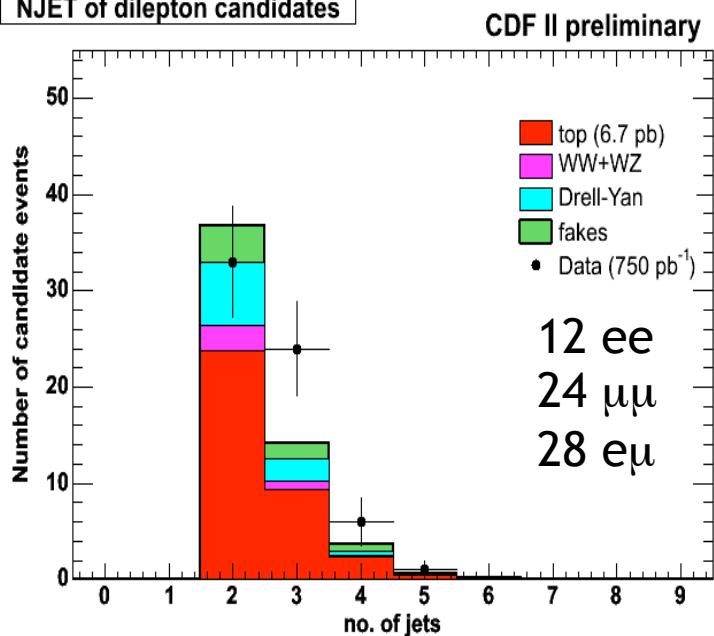
Cross Section in Dilepton channel



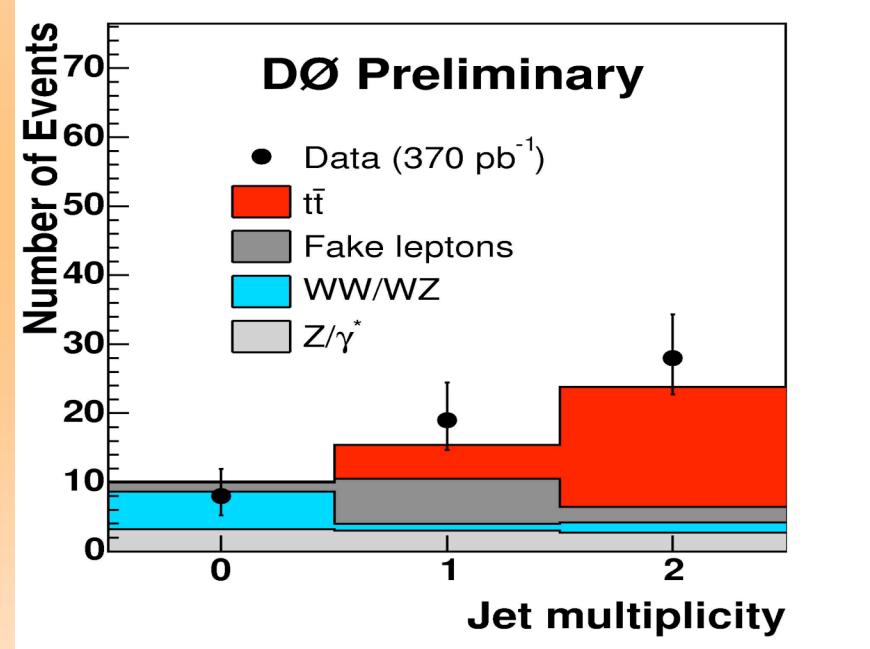
New

$\sim 750 \text{ pb}^{-1}$

NJET of dilepton candidates



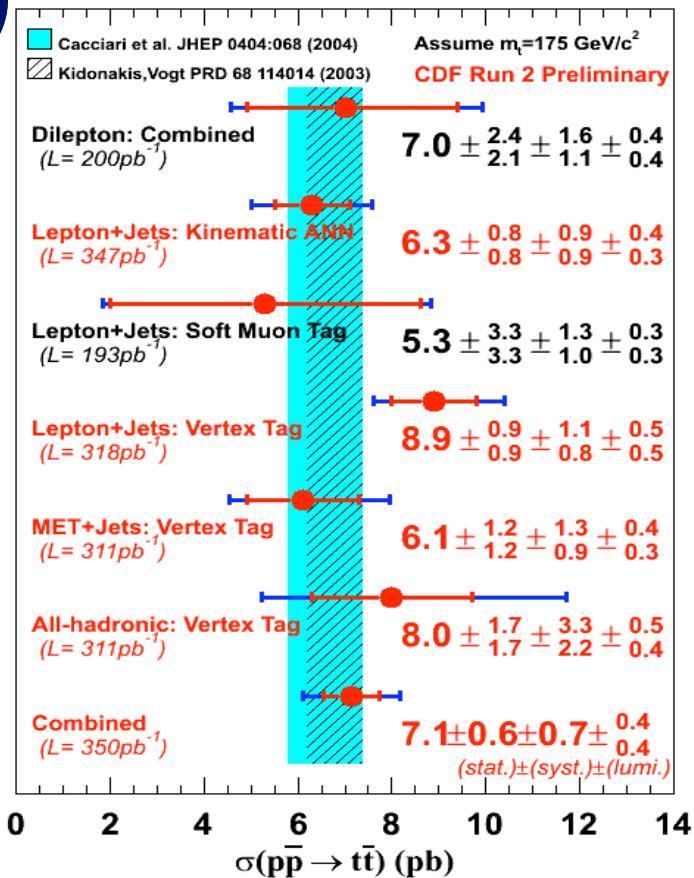
$$\sigma = 8.3 \pm 1.5 \text{ (stat)} \\ \pm 1.0 \text{ (syst)} \pm 0.5 \text{ (lumi) pb}$$



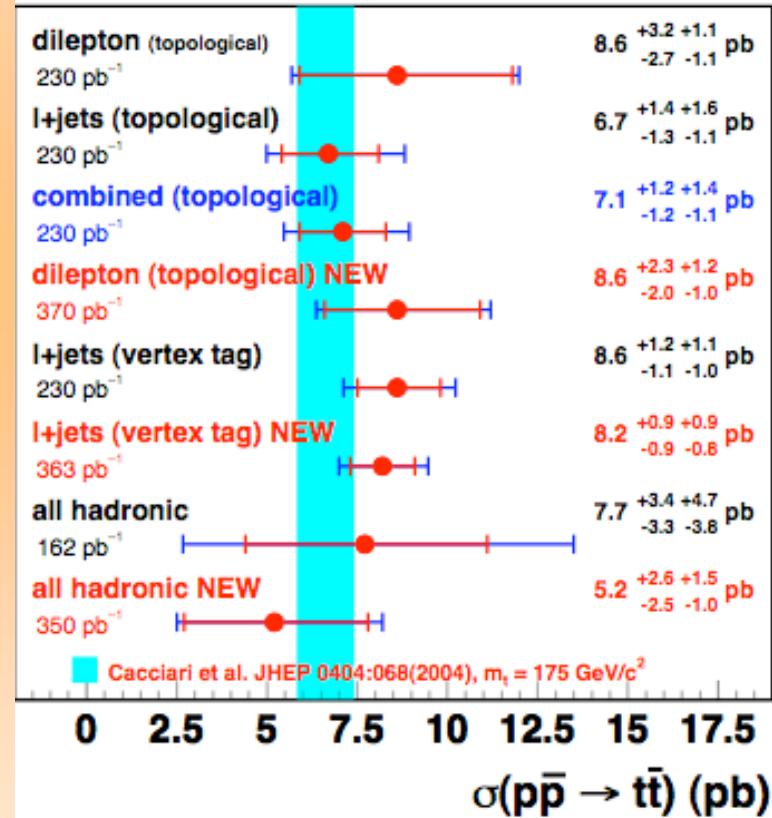
$$\sigma = 8.6 \pm 2.3 \text{ (stat)} \\ \pm 1.1 \text{ (syst)} \pm 0.6 \text{ (lumi) pb}$$



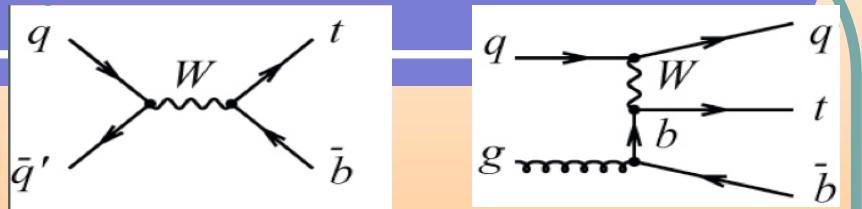
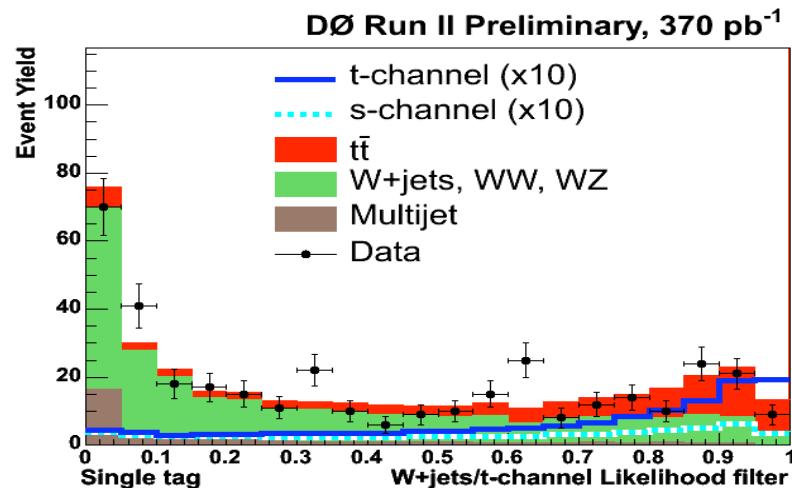
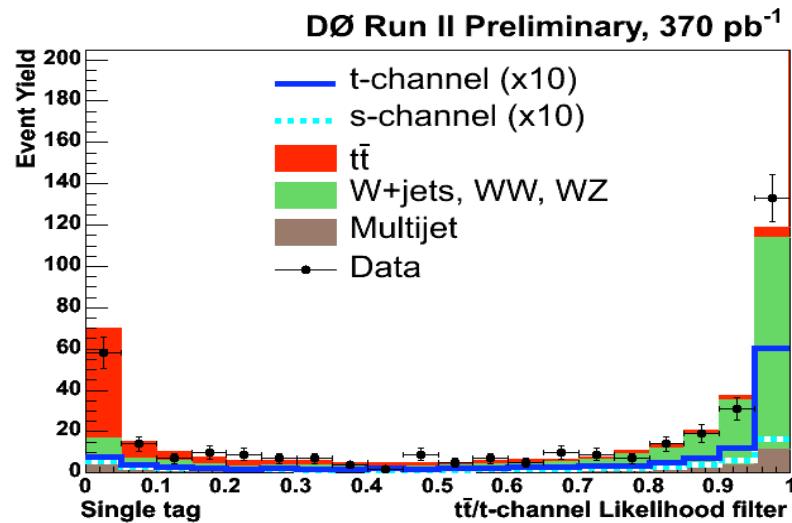
Top Quark Pair Production: Summary



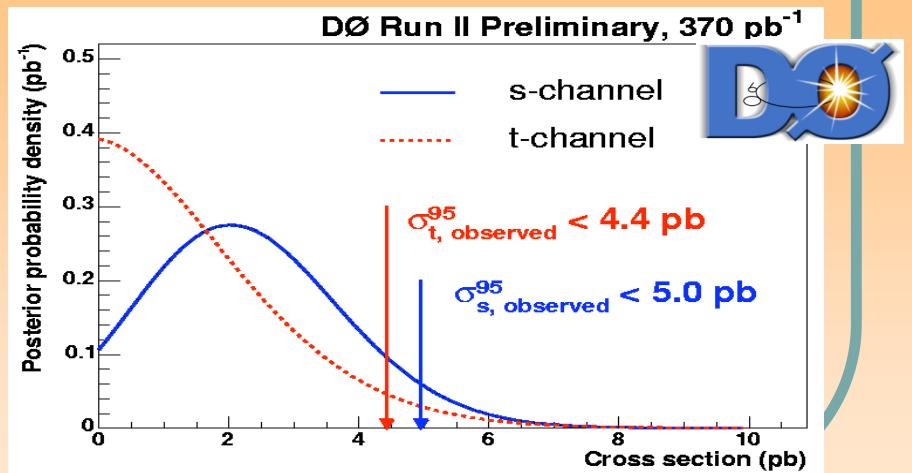
DØ Run II Preliminary



Single Top Search



- $\sigma_s = 0.88 \text{ pb}; \sigma_t = 1.98 \text{ pb};$
- LJ: ≥ 1 b-tag
- Overwhelming W+jets backgrounds
- Dedicated 2D Likelihood fitter
- Best world's upper limits so far
- Expect 3 σ evidence with 2fb-1

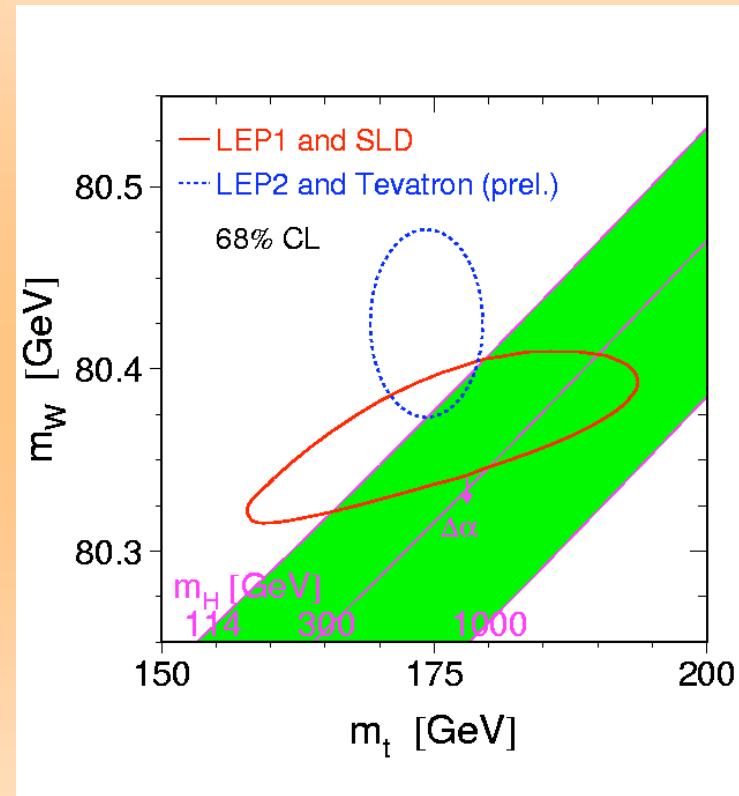
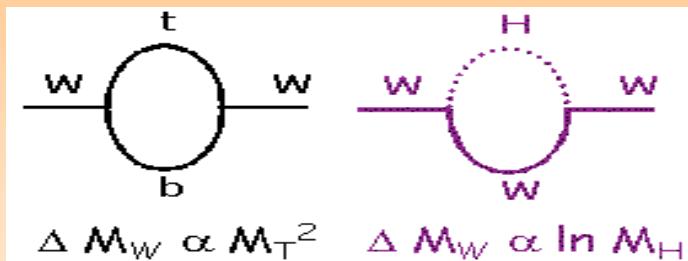


Top Mass Measurements

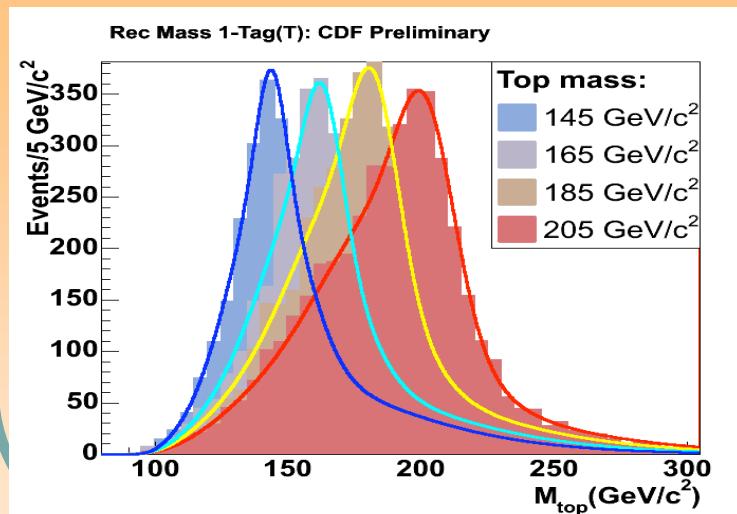
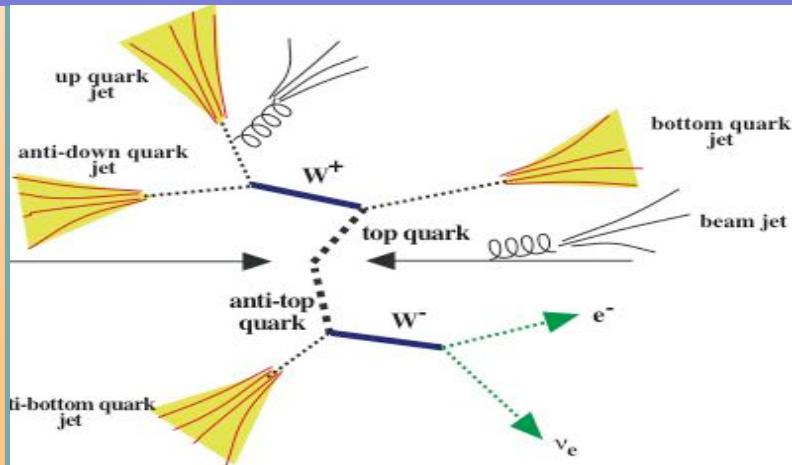


Top mass relation to Higgs

- Top quark mass is a fundamental parameter of SM
- Radiative corrections to SM predictions dominated by top mass
- Together with W mass places a constraint on Higgs mass



CDF Template Method



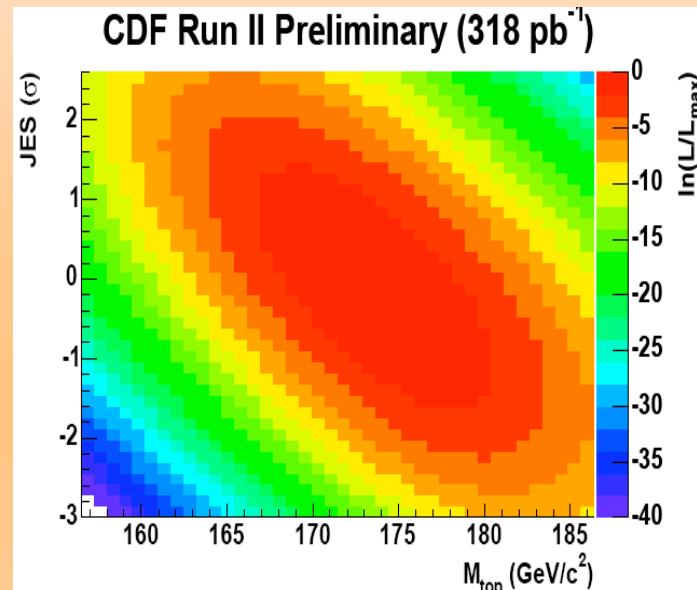
- Constrain $m(jj) = m_W$ and $m(l\nu b) = m(jjb)$
 - 24 possibilities for 0 b-tags
 - 12 possibilities for 1 b-tag
 - 4 possibilities for 2 b-tags
- Select configuration with best χ^2 fit \rightarrow obtain M_{reco}

- 2005 Novelty: Jet Energy Calibration in situ
- Simultaneous fit to invariant mass of $W \rightarrow jj$
- Global JES factor used to correct energies of jet
- Reduces systematic uncertainty

CDF M_{top} Measurement in Lepton+Jets



- Up to date the best single measurement in the world!
- Better than Tevatron Run I average
- Will be shortly updated with $\sim 750 \text{ pb}^{-1}$



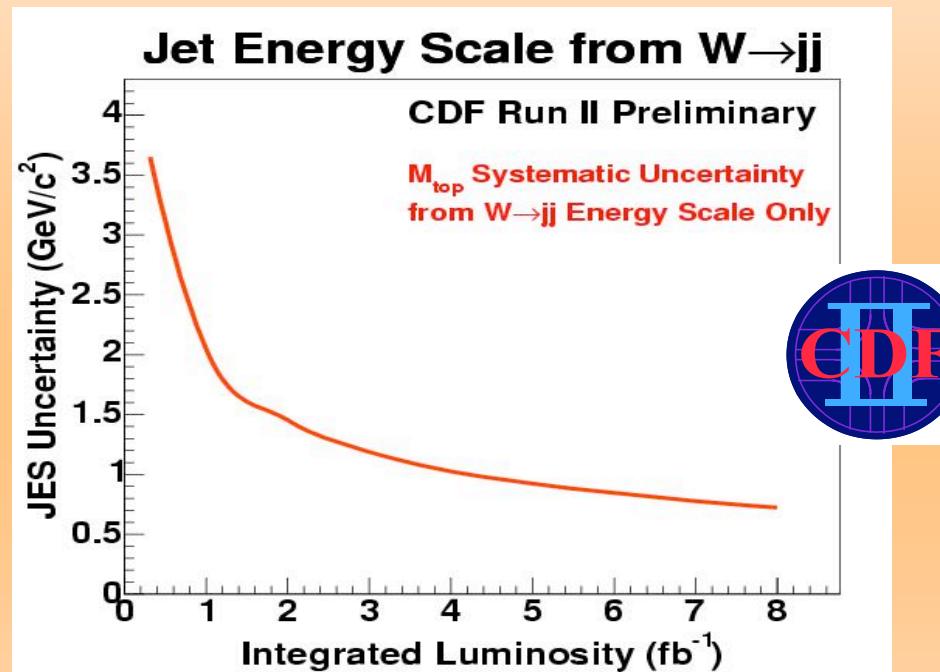
$$m_{top} = 173.5 \pm ^{2.7}_{2.6} \text{ (stat)} \pm 2.5_{(\text{JES})} \pm 1.3_{(\text{syst})} \text{ GeV} / c^2$$

$$\Delta \text{JES} = -0.10 \pm ^{0.78}_{0.80} \sigma_{(\text{a priori})}$$

PRD: [hep-ex/0510048](https://arxiv.org/abs/hep-ex/0510048)
PRL: [hep-ex/0510049](https://arxiv.org/abs/hep-ex/0510049)

Future Projection

Systematic Source	Uncertainty (GeV/c ²)
ISR/FSR	0.7
Model	0.7
b-jet	0.6
Method	0.6
PDF	0.3
Total	1.3
Jet Energy	2.5



- Expect significant reduction in JES uncertainty with more data
- See CDF template results with $\sim 0.7 \text{ fb}^{-1}$ in Winter 2006
- Will be able to achieve 1.5 GeV uncertainty on top mass!

DO Matrix Element Technique

Made best single measurement in Run I

- Form probability for each event:

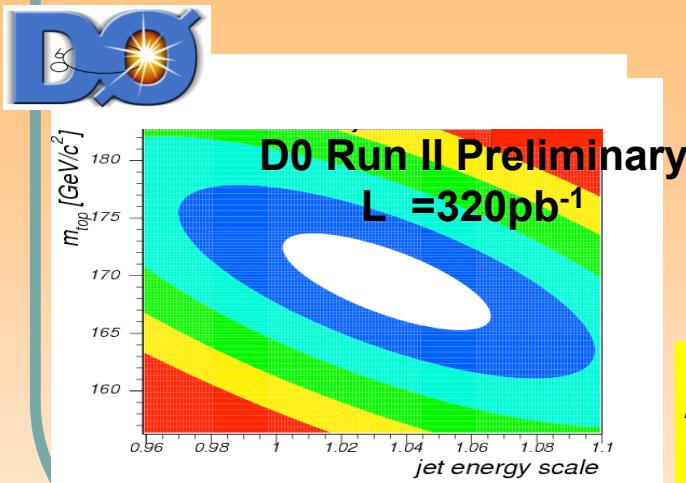
$$P(x; M_{top}) = \frac{1}{\sigma} \int d^n \sigma(y; M_{top}) dq_1 dq_2 f(q_1) f(q_2) W(x, y)$$

- Consider all permutations
- Maximize Likelihood: $\prod_i P^i(x; M_{top})$

$f(q)$: parton density functions

$d^n \sigma$: LO Matrix element

$W(x, y)$: transfer function between jet and parton momenta



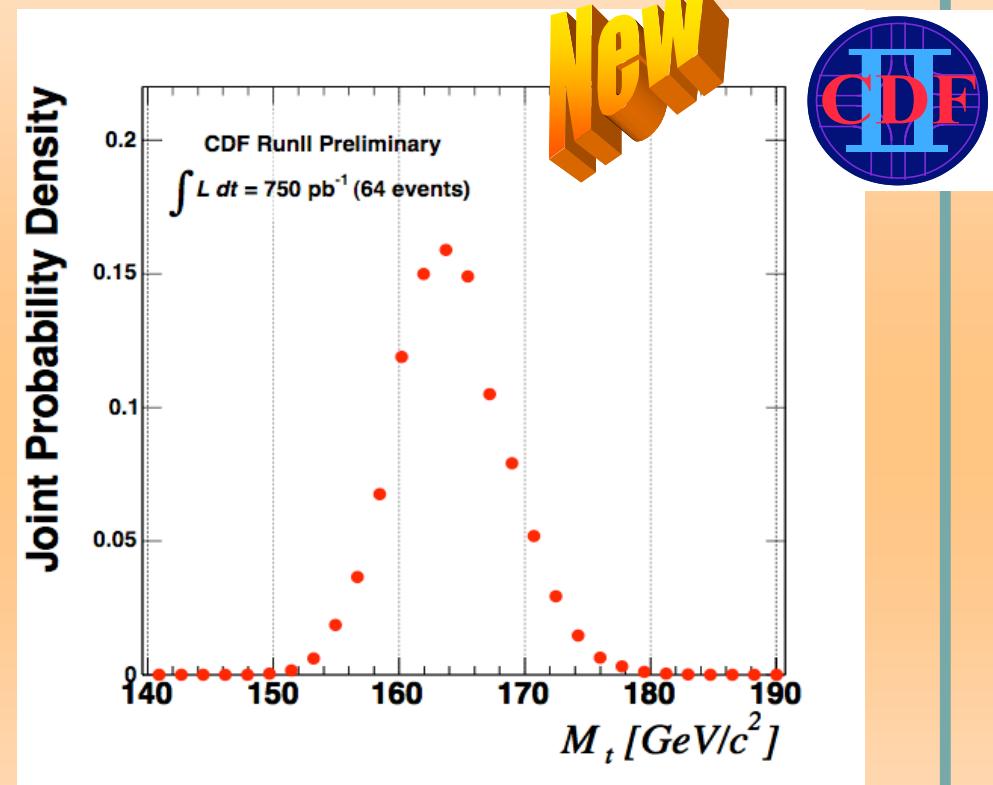
- Use LO ME for ttbar and W+jets
- Run II Improvements: W->jj energy calibration
- No a priori energy determination

$$m_{top} = 169.5 \pm 3.0_{(\text{stat})} \pm 3.2_{(\text{JES})} \pm 1.7_{(\text{syst})} \text{ GeV}/c^2$$

$$\text{JES} = 1.034 \pm 0.034$$

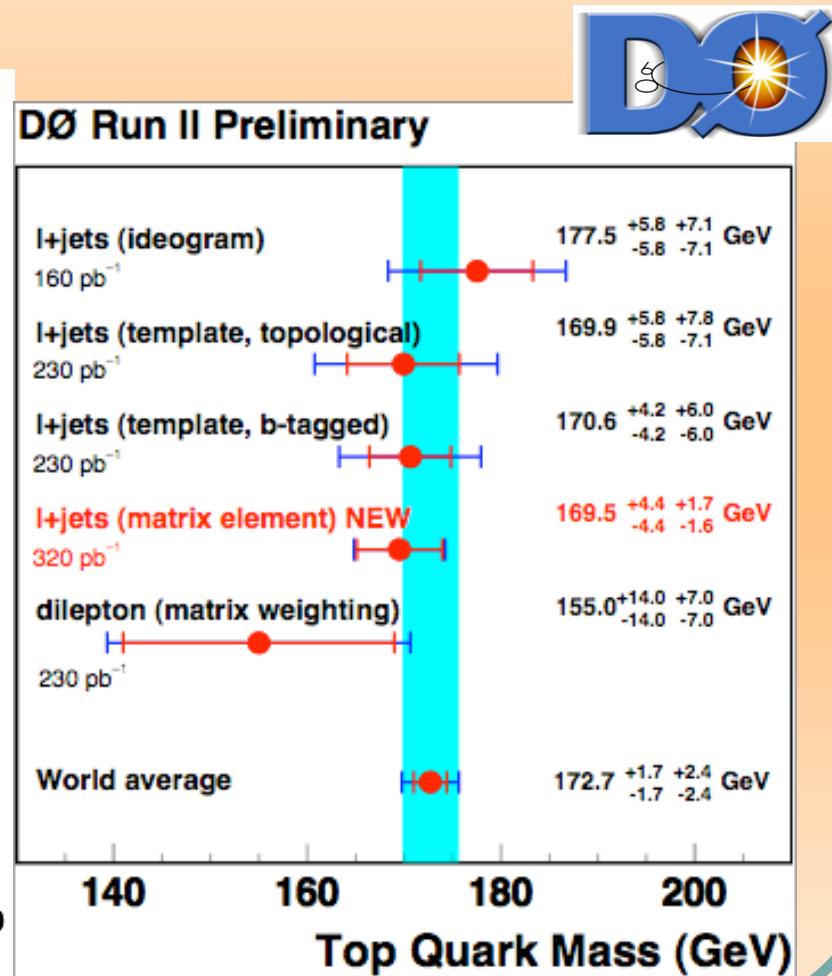
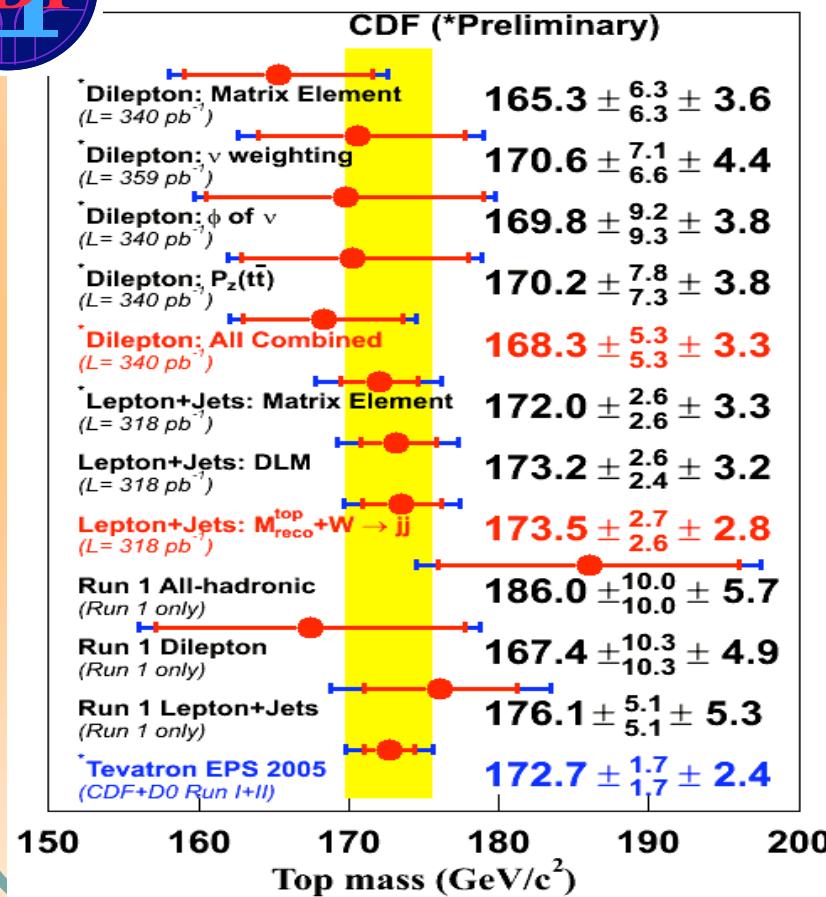
CDF Dilepton Matrix Element M_{top} Measurement (750 pb^{-1})

- DIL mode:
 - Reduced combinatorics
 - Only two possible parton-jet assignments
 - Unconstrained kinematics: two neutrinos in the final state
- Background L0 Matrix Element treatment
- Best single measurement in Dilepton channel!



$$m_{top} = 164.5 \pm 4.5 \text{ (stat)} \pm 3.1 \text{ (syst)} \text{ GeV}/c^2$$

Top Mass: Summary (up to $\sim 360 \text{ pb}^{-1}$)



Searches for ttbar Resonances

$$p\bar{p} \rightarrow X^0 \rightarrow t\bar{t}$$

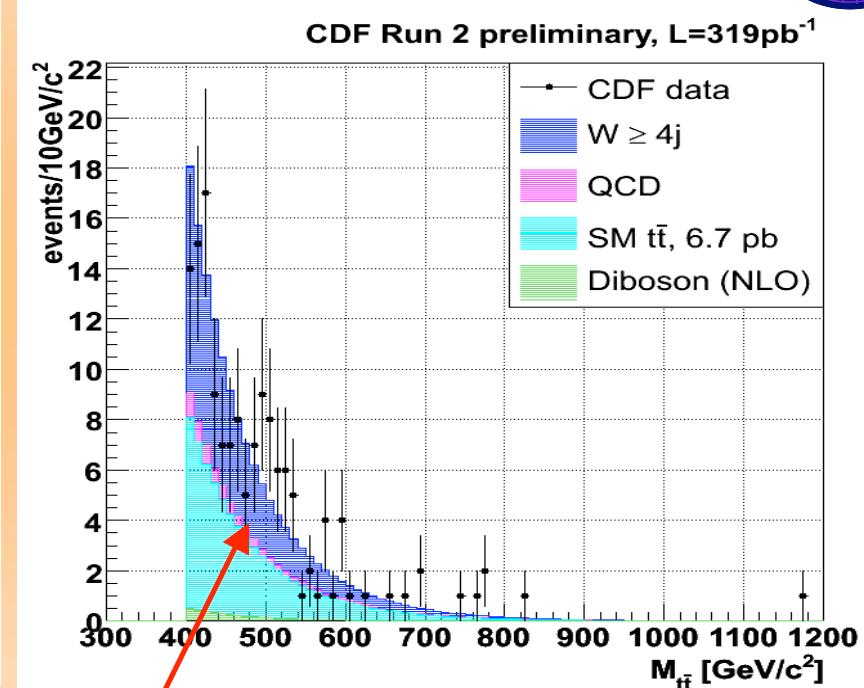
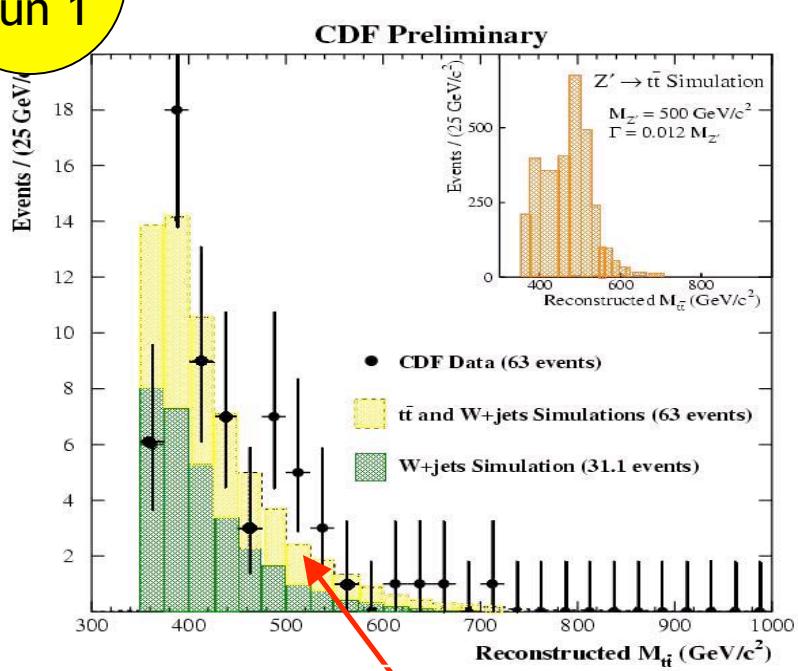
- Various exotic models predict the existence of particles decaying to ttbar: **Topcolor-Assisted Technicolor**
- (Hill, Phys Lett. B345, 483 (1995); Hill and Parke Phys. Rev. D49, 4454 (1994))
- Extends technicolor models and attempts to explain EWSB by introducing a new strong interaction
- Predicts new massive bosons “topgluons” and a topcolor Z'

History: Previous Measurements



CDF
Run 1

- Lepton + jets:



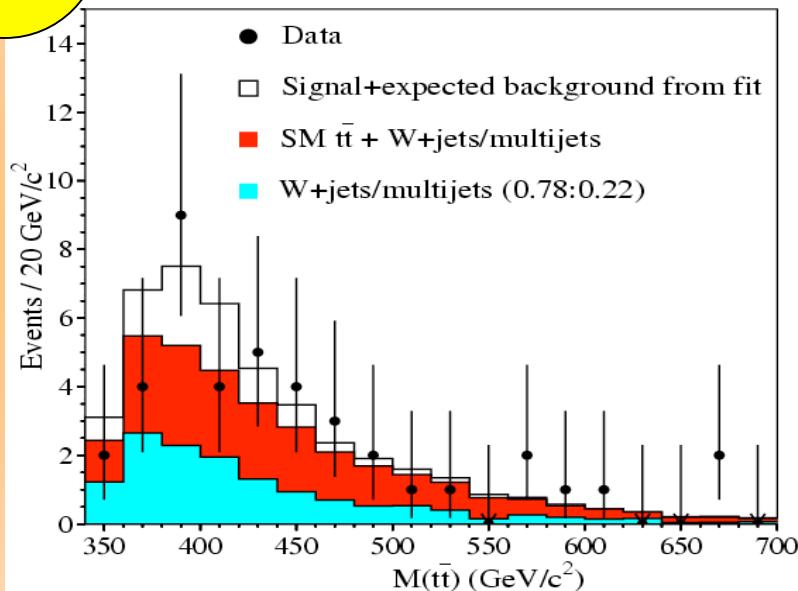
Phys.Rev.Lett. 85, 2062 (2000)

- Observed quite intriguing excess around 500 GeV
- Had a similar although smaller excess in Run 1

D0 searches

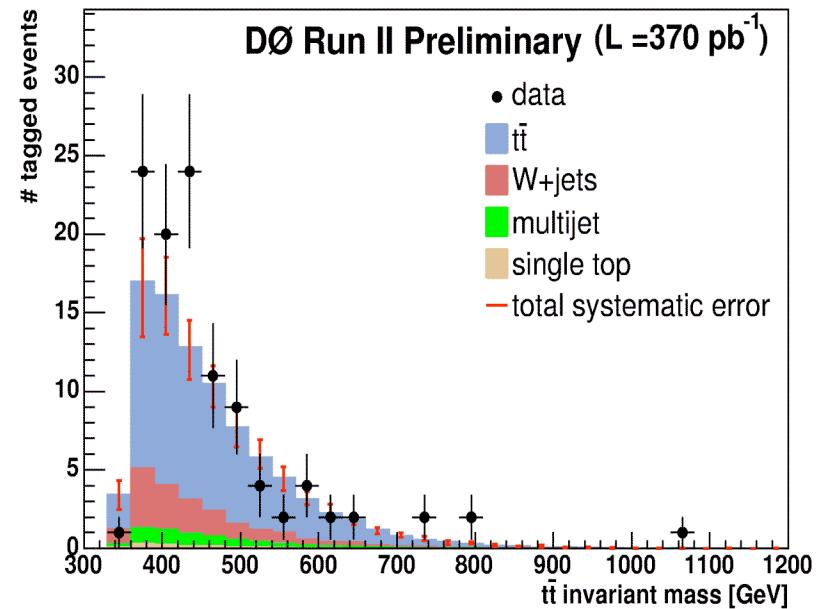
D0
Run 1

- Lepton + jets:



Phys.Rev.Lett. 92, 221804 (2004)

- No similar anomaly seen in D0 data



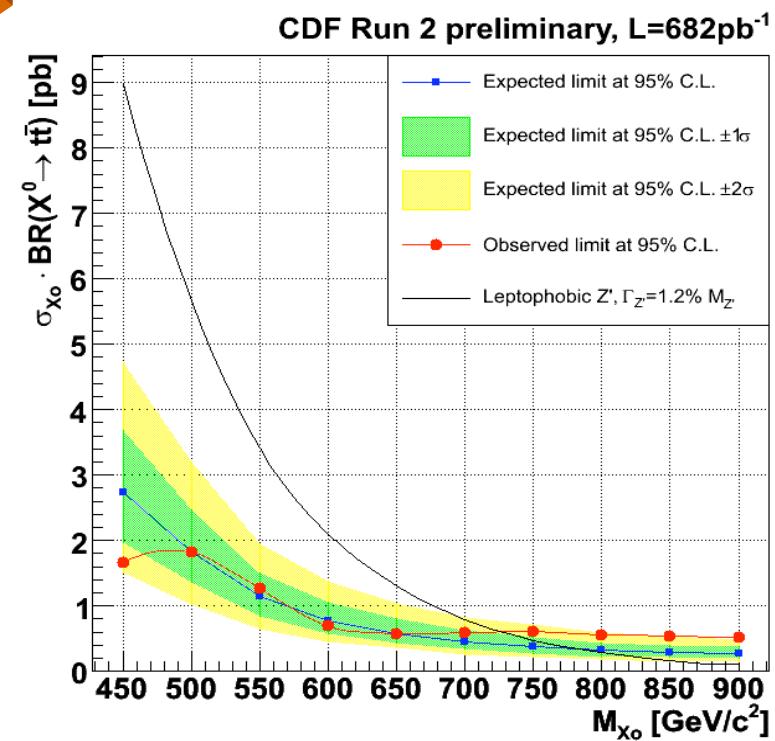
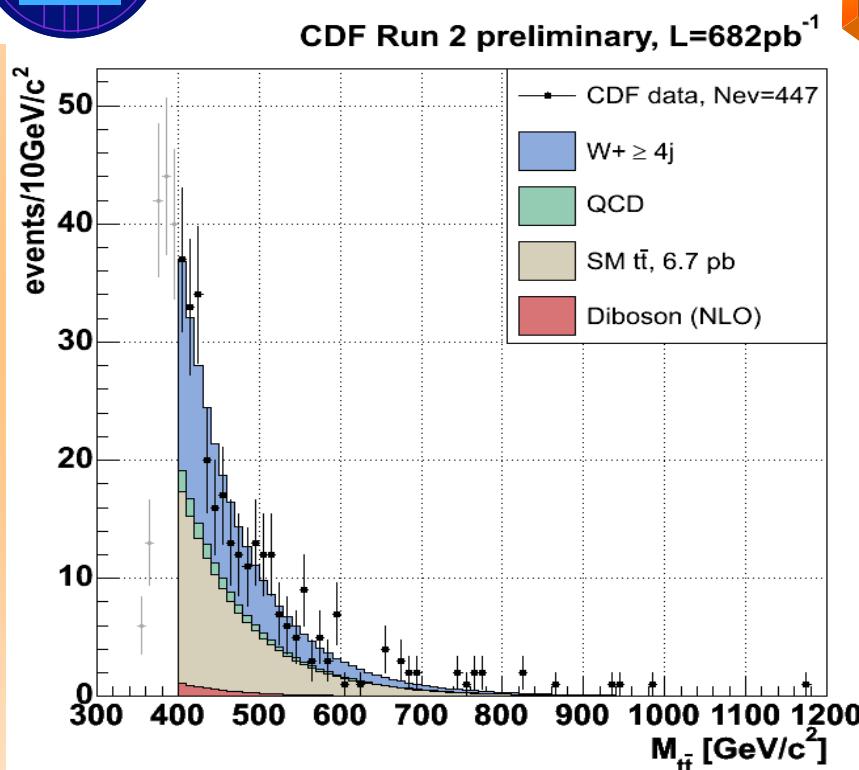
Excluded with 95%CL
 $M_{Z'} < 680 \text{ GeV}$
 $(\Gamma_{Z'} = 0.012M_{Z'})$



Latest CDF measurement (682 pb⁻¹)



New



- Alas! With about twice more data an excess has washed out!

Top Quark Properties

- I will cover only the latest measurements:
 - Top Charge
 - Top lifetime
 - New heavy top in the top sample?

Top Charge

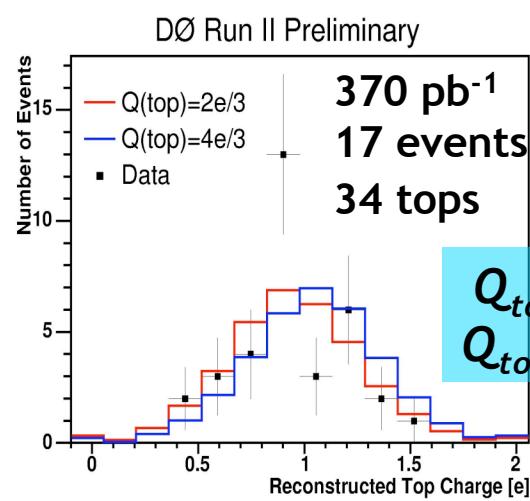
- Is it the Standard Model top ?
- W.-F. Chang et al., Phys. Rev. D 59, 091503 (1999), (hep-ph/9810531) proposes an exotic doublet of quarks $(Q1, Q4)_R$ with charges $(-1/3, -4/3)$ and $M \sim 175$ GeV
- Right-handed b quark mixes with the isospin $+1/2$ component
- while $M_{top} \sim 274$ GeV escaped detection
- $q = -4/3$ is consistent with EW data, new b-couplings improve the EW fit (E. Ma et al. , hep-ph/9909537)

Top Quark Charge Measurement

Lepton+jets, double b-tag events

Determine:

- charge of W (lepton)
- pairing between W and b (χ^2 fit)
- flavor of b-jet



Jet Charge:

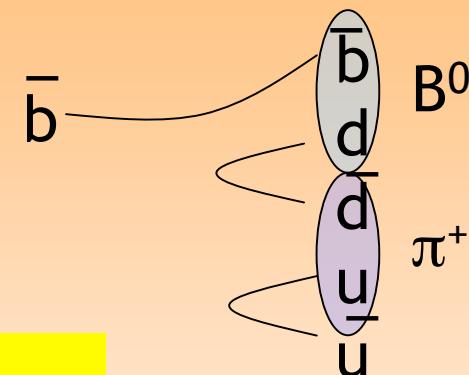
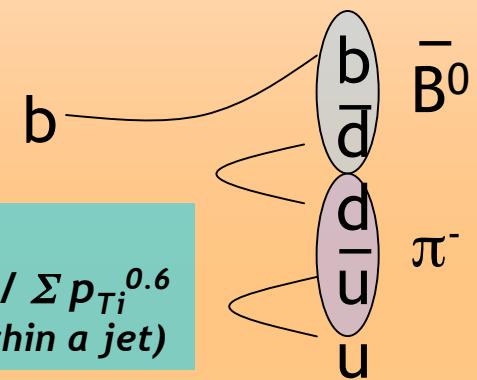
$$Q_{jet} = \sum q_i p_{Ti}^{0.6} / \sum p_{Ti}^{0.6}$$

(sum over tracks within a jet)

$$Q_{top,1} = |q_l + q_{b(l)}|$$
$$Q_{top,2} = |-q_l + q_{b(j)}|$$

Perform likelihood ratio test:

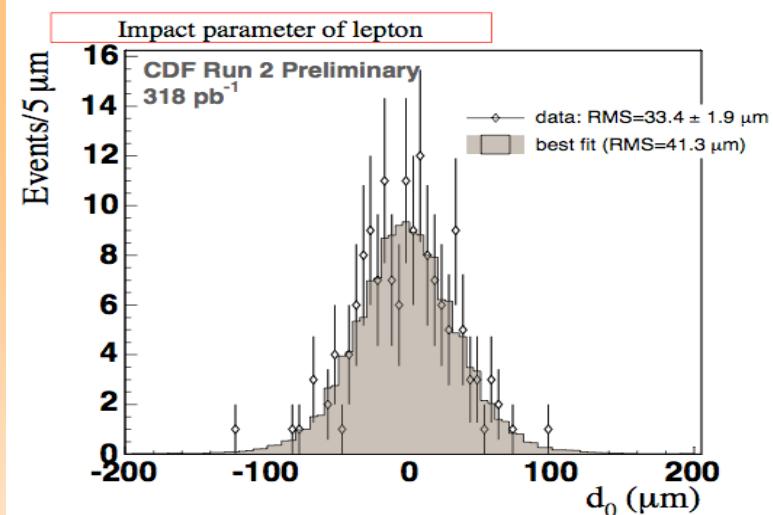
Excluded Q=4/3 with 94%CL



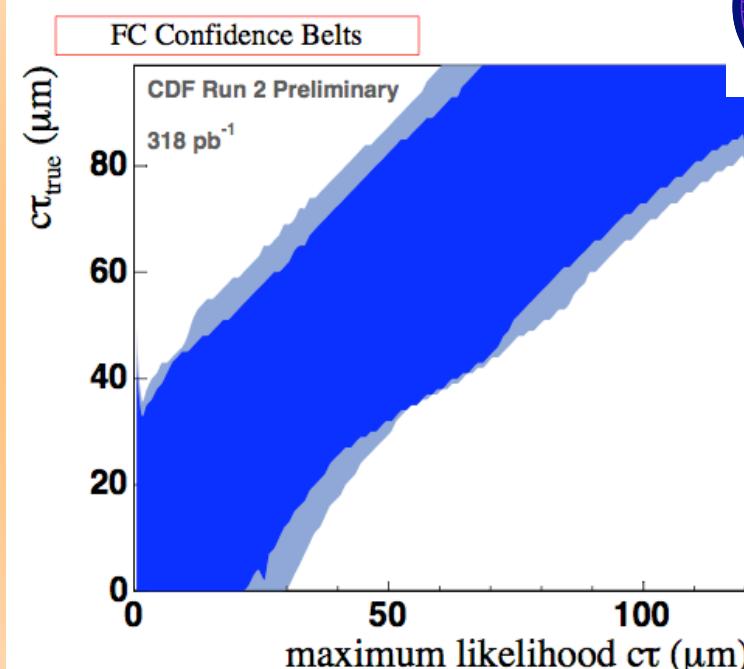
Top Lifetime

- Within the SM $\tau_{\text{top}} \sim 10^{-24} \text{ s}$
- Long-lived top?
- Use d_0 -lepton impact parameter with respect to beamline
- Determine detector resolution from

$Z^0/\gamma \rightarrow e^+e^-/\mu^+\mu^-$



Fit combination of signal/BG templates to the data: lepton+jets with ≥ 1 b-tag



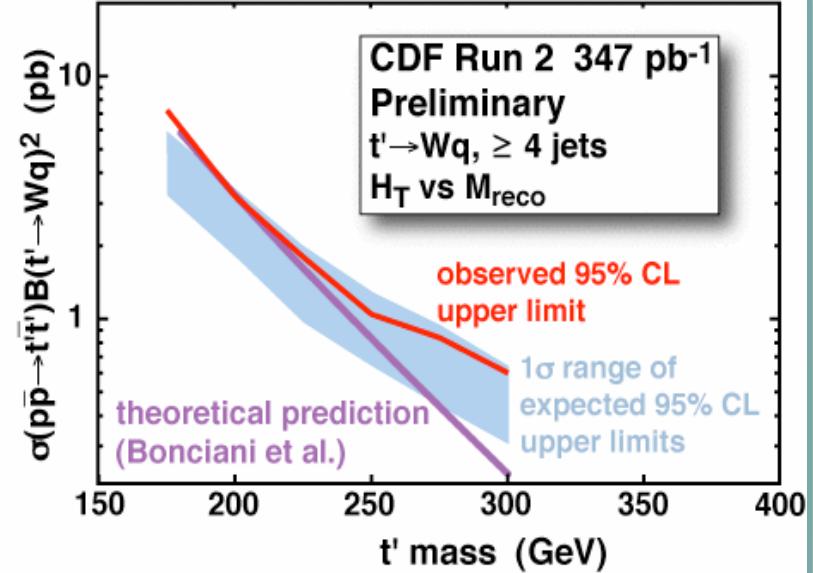
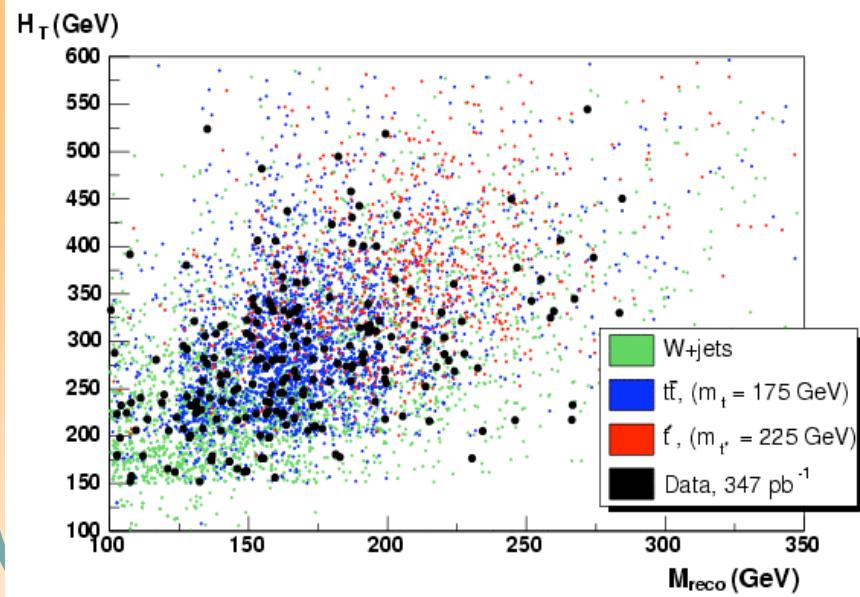
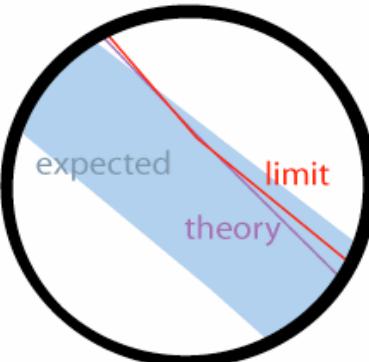
$c\tau < 52.5 \mu\text{m}$ with 95% CL



New Heavy Particles Decaying to Wq?

- Can be a fourth generation up-type quark
He/Polonsky/Su (hep-ph/0102144)
a generic 4th chiral generation is consistent with EWK data;
accommodates a heavy Higgs (500 GeV) without any other new physics
- “Beautiful Mirrors” model
Wagner et al (hep-ph/ 0109097)
predicts a new heavy up-type quark decaying to Wb; naturally
accommodates the LEP b forward-backward asymmetry results
- From the precision EWK data the mass splitting between a t' and a
b' quark is relatively small. Therefore if $M_{t'} < M_{b'} + M_W$: $t' \rightarrow W$
 $b(q)$ (promptly)
- CDF Search in Lepton + jets channel: 2D-fit with
 - H_T = sum of transverse momenta of all objects in the event
 - M_{reco} from χ^2 -fit

Search for $t' \rightarrow Wq$



- Set a limit on 4th generation up-type quark pair production
- Data did not cooperate well

Excluded t'
 $196 < m_{t'} < 207 \text{ GeV}$

Conclusions

- Many other analyses utilizing datasets of integrated luminosity $\sim 700 \text{ pb}^{-1}$ are being finalized
- Results will be presented at the forthcoming Winter conferences
- No evidence for the top quark being non-Standard Model so far
- More precise measurements of the top mass and other quantities coming soon